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TITLE PLANETARY SKIN GAMES

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Planetary Skin Games

Meteorites and the lunar surface have long been the objects of space exposure studies. The skins of these space travelers are the interface between quiescent, stabilized, and segregated interiors and the often savage energies - meteorite impacts, cosmic rays, and solar emissions - that move through the vacuum of space. These skins contain nuclear and chemical products of space radiation as well as small fragments of themselves dispersed by meteorite bombardment. The interpretation of these fragments and aging effects, however, is far from clear-cut. The 19th Lunar and Planetary Science Conference provided more progress in measurement, but also showed that maturing research is more apt to uncover new complexity than it is to provide pat answers.

Analysts of cosmogenic (cosmic-ray-produced) nuclides are wrestling with the needs for a better understanding of the production rates of these isotopes, especially as a function of the sample's chemistry and shielding (its location in the parent object and that object's size and shape). Most reported results were based on high-sensitivity measurements using conventional mass spectrometry for noble-gas isotopes and accelerator mass spectrometry for long-lived radionuclides. The payoff from such studies will be an eventual understanding of where and when meteoritic fragments were separated from their parent bodies, of the histories of lunar samples, and of the patterns and causes of long-term variation in the fluxes of galactic cosmic rays and of energetic nuclei from the sun.

A variety of measurements on lunar samples and chondritic meteorites were used to test calculated production rates or to determine solar-proton fluxes. Jeffrey Klein (University of Pennsylvania), Gregory Herzog (Rutgers University), and others used profiles of $7X10^5$-year ^{26}Al and $1.5X10^6$-year ^{10}Be in lunar rock 74275 to study the averaged fluxes of energetic protons from the Sun over the last 10^6 years. The measured concentrations of ^{26}Al in the rock's top centimeter were slightly more than expected from similar measurements on other lunar rocks but could be related to different rock compositions. Claudio Tuniz (Univ. degli Studi, Trieste, Italy), Klein, Herzog, and others measured ^{26}Al and ^{10}Be in seven samples from the H5 chondrite Bur Gheluai. This data suite implies that Bur Gheluai must have been very large in space (radius > 100 cm) or had a 2-stage irradiation. Kunihiko Nishiizumi (University of California, San Diego) and others reported measurements of $3X10^5$ year ^{36}Cl in a lunar core and in the metal phases of cores from the St. Severin and Jilin chondrites. Calculated ^{36}Cl production rates differed from the measured activities and showed the need for better cross sections for the reactions of neutrons and low-energy protons. Ludolf Schultz and Frederich Begemann (Max Planck Institute for Chemistry, Mainz, FRG) showed that shielding- and chemistry-corrected production ratios of cosmogenic nuclides (e.g., ^{22}Ne/^{21}Ne) varied with the bulk chemistry of the meteorite, especially the total iron content. Otto Eugster (University of Bern, Switzerland) determined the exposure ages of 17 chondrites by the ^{81}Kr-Kr method and, with measured concentrations of other noble-gas isotopes and known factors for chemistry, determined production rates of ^{3}He, ^{21}Ne, ^{38}Ar, ^{83}Kr, and ^{126}Xe as a function of the shielding indicator ratio ^{22}Ne/^{21}Ne.

Other studies used simulations at high-energy proton accelerators to study production systematics of cosmogenic nuclides or reported results for cosmogenic nuclides in terrestrial samples. Peter Englert (San Jose State University), A.J.T. Jull (University of Arizona), and others measured ^{14}C in a thick target that had been irradiated by 2.1-GeV protons. They found that ^{14}C production by secondary neutrons was important and thus ^{14}C production rates will be sensitive to shielding. Robert Reedy (Los Alamos National Laboratory), Klein, Nishiizumi, and others measured ^{26}Al, ^{10}Be, and other radionuclides made in quartz irradiated with muons or energetic neutrons. Their results will enable calculations of rates for the production of these nuclides in-situ for rocks on or in the Earth's surface. Stephen Finney and Charles Sonett (University of Arizona) studied the variations in the ^{14}C activities measured in tree rings using a new Bayesian statistical algorithm that allows high-resolution spectral analysis for the irregularly spaced ^{14}C data over the last ~7000 years from two laboratories. They found 16 periods between 208 and 2300 years common to both data sets that could result from only four basic periods of unknown origins.

The regolith-like howardites and the chondrites contain trapped gasses and cosmic ray induced isotopes that still puzzle researchers. In a pair of studies, A. Pedroni, R. Wieler, P. Signer, and H. Baur (ETH Zurich) suggested that the high ^{21}Ne content of chondritic constituents (in Fayetteville and the howardite Kapoeta) may be due to prolonged pre-compaction exposure (more than 20 My) and need not be attributed to an energetic T Tauri solar phase. R. Sundar Rajan (Jet Propulsion Laboratory) and Gunter Lugmair (Scripps Institute of Oceanography) also examined Kapoeta and Fayetteville, and from the absence of correlation between ^{150}Sm (a neutron capture product at ~1m regolith depth) and solar flare tracks (an active-sun product at the regolith surface) also suggested that a T-Tauri solar phase is not required. Trapped xenon may be another key to help unlock this puzzle. Bernard Lavielle and Kurt Marti (University of California, San Diego) reported that a low-temperature combustion technique removed most trapped xenon and allowed other xenon components to be more readily detected.

Much study has been devoted to mesosiderites, those stony-iron meteorites that are brecciated mixtures of basalts and iron. Alan Rubin and Eric Jerde (University of California, Los Angeles) have found sharp lanthanide-element differences between gabbro and basalt fragments in the mesosiderite Vaca Muerta. They suggest that impact heating has remelted cumulate gabbros and permitted extraction of lanthanide-rich (except Eu) liquids, leaving behind a lanthanide-poor gabbro residue. David Mittlefehldt (Lockheed EMSCO, Houston) compared the regolith-like silicate portions of several mesosiderites with howardites, and concluded that mesosiderites are a mixture including deeper portions of their parent body. In an interesting set of experiments, B. Pavri, R. Greenberg, C.L. Broadhurst, and M.J. Drake (University of Arizona) tried to produce both pallasites (olivine-iron) and mesosiderites (basalt-iron) in the laboratory. Pallasites proved relatively easy to make, by putting metal on top of olivine and melting. Mesosiderites were much more difficult, as the metal tends to melt the basalt before the appropriate "metal injection" texture is formed. Speed and quenching seem to be critical to mesosiderite formation. Donald Bogard and Jim Jordan (NASA, Johnson Space Center) worked with Mittlefehldt to obtain $^{39}Ar/^{40}Ar$ stepwise heating ages for several mesosiderites. They found a consistent age distribution between 3.8 and 3.6 Gy; whether metamorphism or formation, this cluster suggests major parent body disruption at less than 4.0 Gy.

Meanwhile, back on the Moon, theoretical and experimental studies are adding to the more common sample-based analysis of the regolith. Mark Cintala and Friedrich Horz (NASA, Johnson Space Center) have begun to scale their regolith evolution experiments by using dimensional analysis. From many variables they extracted all possible dimensionless groups and, from the simplest and most reasonable permutations, determined that the ratio of comminuted target mass to projectile mass can be predicted as a function of target grain size, impact velocity, and the projectile's size, density, and diameter for a wide range of targets and projectiles. Abhijit Basu and Carol Bangs (Indiana University) have tackled the problem of statistically determining the proportion of agglutinates and breccias that have been recycled (a property that is not necessarily evident from sample analysis). Combined with sample analysis, this method may extend interpretation of maturity beyond simple comparison of directly measured chemical or physical maturity parameters.

The often-made argument that regolith contains the widest range of variants from a limited planetary sampling is proving as true for regolith breccias as it is for loose regolith. Dave Vaniman and Grant Heiken (Los Alamos National Laboratory) with Paul Warren and Eric Jerde (University of California, Los Angeles) found three of 29 Apollo 14 regolith breccias to be different from their Apollo 14 host soils. One of these regolith breccias (14076) is particularly bizarre and contains fragments of what appears to be a new silica-poor mineral with stoichiometry near $Ca_3Al_6Si_2O_{16}$ (confirmation dependent on further x-ray diffraction study). Jonathan Sadow (University of Houston) used quantitative petrography to compare the "chondrules" in Apollo 14 regolith breccias with chondrules from meteorites. The lunar "chondrules" are smaller, more restricted in size range, and dominated by plagioclase. Basu reported on faint textures in three Apollo 16 regolith breccias that suggest the first reported example of graded bedding in lunar samples, possibly generated in decelerating suevite-like flows.

Although the flurry of sample processing from the heady days of the Apollo missions has died down, there are still some unopened packages under the tree. New core dissection (79001/2) has resulted in new knowledge. David McKay (NASA, Johnson Space Center), Susan Wentworth (Lockheed EMSCO, Houston), and Basu collaborated on a study of this core that has confirmed that the upper 8.5 cm is the most extreme example of mixing between agglutinate-saturated and ferromagnetically-aged soil components. John Stone and Robert Clayton (Enrico Fermi Institute, Chicago) find these same end-members in nitrogen isotope mixing, and constrain the mixing event to have occurred within the last 300 My. Everett Gibson (NASA, Johnson Space Center), Roberta Bustin (Arkansas College), and Patricia Mannion (Earlham College, Indiana) determined hydrogen abundances in 79001/2 samples as well as in the Apollo 16 and 17 deep drill cores, and reported that hydrogen abundances match closely with ferromagnetic maturity. This match might be used to predict hydrogen abundances for resource extraction, based on maps of regolith maturity and chemistry. New samples of lunar regolith are in preparation: Carol Schwarz (Lockheed EMSCO, Houston) has begun opening an Apollo 15 drive tube (15009) that will provide another 29 cm of new lunar regolith samples. Thus we can anticipate new knowledge as well as retrospection at next year's conference, the epochal 20th anniversary of lunar sample studies.

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